MEASUREMENTS OF ESTUARINE SHRIMP DENSITIES
APPLIED TO CATCH PREDICTIONS

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ABSTRACT

New methodology was used to determine densities of brown shrimp (Penaeus aztecus), white shrimp (P. setiferus) and other species in a Galveston Bay salt marsh. These density measurements permitted comparisons of abundances between habitats and realistic estimates for projections of standing stocks. The data were obtained using a cylindrical drop sampler that encloses 2.8 m of marsh bottom. The method was compared against other techniques traditionally employed in estimating shrimp abundances. In side-by-side shallow water sampling on bottoms without vegetation, a 1-m wide beam trawl, 5.5-m wide bag seine and 3.7-m wide otter trawl were 82, 33 and 17% as efficient, respectively, as the drop sampler in catching shrimp. With marsh vegetation present, the 1-m wide beam trawl was 23% as efficient as the drop sampler. Standing stock estimates extrapolated from drop sampler density measurements to 90 acres were similar to mark-and-recapture estimates covering the same area. In a small pond (172 m) with 1,200 white shrimp, the stock estimate using six drop samples was 1,166. The major disadvantage for estimating stocks is that drop sampler data reflect natural patchiness in distributions, which often results in higher variances than methods that integrate patches.

INTRODUCTION

The size and success of the shrimp fishery in the northern and western Gulf of Mexico each year depend upon the number of postlarvae recruited into estuaries and upon the growth and survival of juveniles in estuarine nurseries (Gunter 1950; Chin 1960; Loesch 1965; St. Amant et al. 1966; Barrett and Gillespie 1973; Gaidry and White 1973; Johnson 1975). In accordance, the abundances of juvenile shrimp in estuaries can provide an estimate of future yield for fishermen (Berry and Baxter 1969).

The primary impediment to predicting annual shrimp yield is the

reliability of data upon which predictions are based. At the core of the problem is acceptance of relative abundance estimates, without qualification, from traditional sampling techniques. Commonly used sampling devices, such as trawls and seines, vary in catch efficiency depending upon circumstances, and the resulting errors are incorporated into abundance data. These errors translate into poor estimates of standing stock for shrimp and other fishery species. Using such data, spatial and temporal comparisons are virtually impossible. Our aim has been to examine this sampling problem and develop methodology that can accurately depict shrimp densities as well as reliably assess stocks in estuarine habitats.

Several predictive techniques have been used that focus on the early life-stages of shrimp. One of the earliest and most commonly used is the postlarval index devised by Baxter (1963) to measure the relative abundance of postlarvae immigrating into estuaries from the Gulf through major passes (Baxter and Renfro 1967). A modification of the technique (Pullen et al. 1968) has extended abundance assessment to older postlarvae and juveniles in shallow-water nursery areas. Abundances of yet larger bait-sized juveniles are also assessed for prediction using different methods (Klima et al. 1982) in deep-water estuarine and bay areas. Each of these techniques relies upon trawls, seines or nets of various types to sample not the actual number of shrimp present but a relative number indicative of abundance. Such samples are acquired under a variety of environmental circumstances during a period when life stage and behavioral characteristics of the shrimp are changing rapidly. The effect of many unaccountable variables on catch efficiencies has made it difficult to compare relative abundance data (for use in prediction) among techniques or across conditions. Some relationships, however, can be established. First, it is apparent that the accuracy in predictive resolution for each technique is greatly dependent upon consistency in measurement of relative abundances. Whatever the circumstances, the mechanical error in sampling (catch efficiency) must remain the same or be corrected for as changes occur. The second is that measurements of abundance for future yield prediction from later life stages (such as bait-sized juveniles) will be better than measurements from earlier stages (such as postlarvae), simply due to nearness in time to harvest. Third, fishery dependent measurements used for prediction are likely to be biased reflecting catch rather than abundance.

Since one or all of the above may confound prediction of shrimp yield, changes should be considered to determine where corrective measures in technique are appropriate or possible. Variability in relative abundances due to changing efficiency of sampling gear and the inability to standardize catchability between samples, even when using the same sampling gear, appears to be the biggest impediment to good prediction. The simple solution may be to apply sampling that

reliably measures actual densities. In a recent study (Zimmerman et al. 1984; Zimmerman and Minello in press), a drop sampler technique was used in an attempt to measure actual densities of brown shrimp (Penaeus aztecus) and white shrimp (P. setiferus) in a Galveston Bay salt marsh. The technique was designed to permit valid comparisons of shrimp densities between differing shallow-water habitats. The measurements provided a reference for evaluating other methods that estimate shrimp population size including those using trawls, seines, and mark-recaptures. In the following, the merits and disadvantages of applying such methodologies to predicting shrimp yields are discussed.

METHODS

A cylindrical drop sampler enclosing 2.8 m^2 (Fig. 1) was designed for obtaining accurate measurements of natant macrofauna in marsh habitats. A descriptive account of the sampler and methods, the salt marsh study site, and the study design are given in Zimmerman et al. (1984). To partly evaluate effectiveness, recovery of shrimp enclosed by the drop samplers was tested. Fifty juvenile shrimp, of sizes from 23 to 91 mm in total length, were marked by clipping a uropod and placed into samplers deployed in vegetated and nonvegetated habitats. After a 30-minute adjustment period, the procedure for removing organisms was followed and recovery was recorded. The test was repeated four times in each habitat. In another different test, the accuracy of the drop sampler was evaluated by comparing an estimate of population size extrapolated from drop sampler measurements taken in a shallow pond containing 1,200 white shrimp. Prior to the test, the 8.5 x 20.2 m (172 m^2) pond (uniformly sloping to 85 cm in depth along the long central axis) was drained and all organisms were removed. Shrimp from a nearby natural marsh area were collected with an otter trawl and placed in the refilled artificial pond. Six drop sampler cylinders (2.8 m , each; Fig. 2) were deployed to equally sample the ends, sides and middle of the pond. Mean density, calculated from the samples, and total area were used to estimate population size and compare against the actual number of shrimp present. Since samples were stratified, density contours were also plotted to evaluate nonrandomness in the shrimp distribution pattern. This provided a useful assessment of error attributable to variation in densities among patches of shrimp.

In other evaluations, densities of shrimp derived using drop samplers in a natural marsh system were compared against relative abundances over areas swept by a 1-m wide beam trawl, a 5.5-m wide bag seine, and a 3.7-m wide otter trawl. Initially, eight pairs of samples from vegetated (Spartina alterniflora) and nearby non-vegetated (sandy mud) habitats were taken using both the 1-m beam
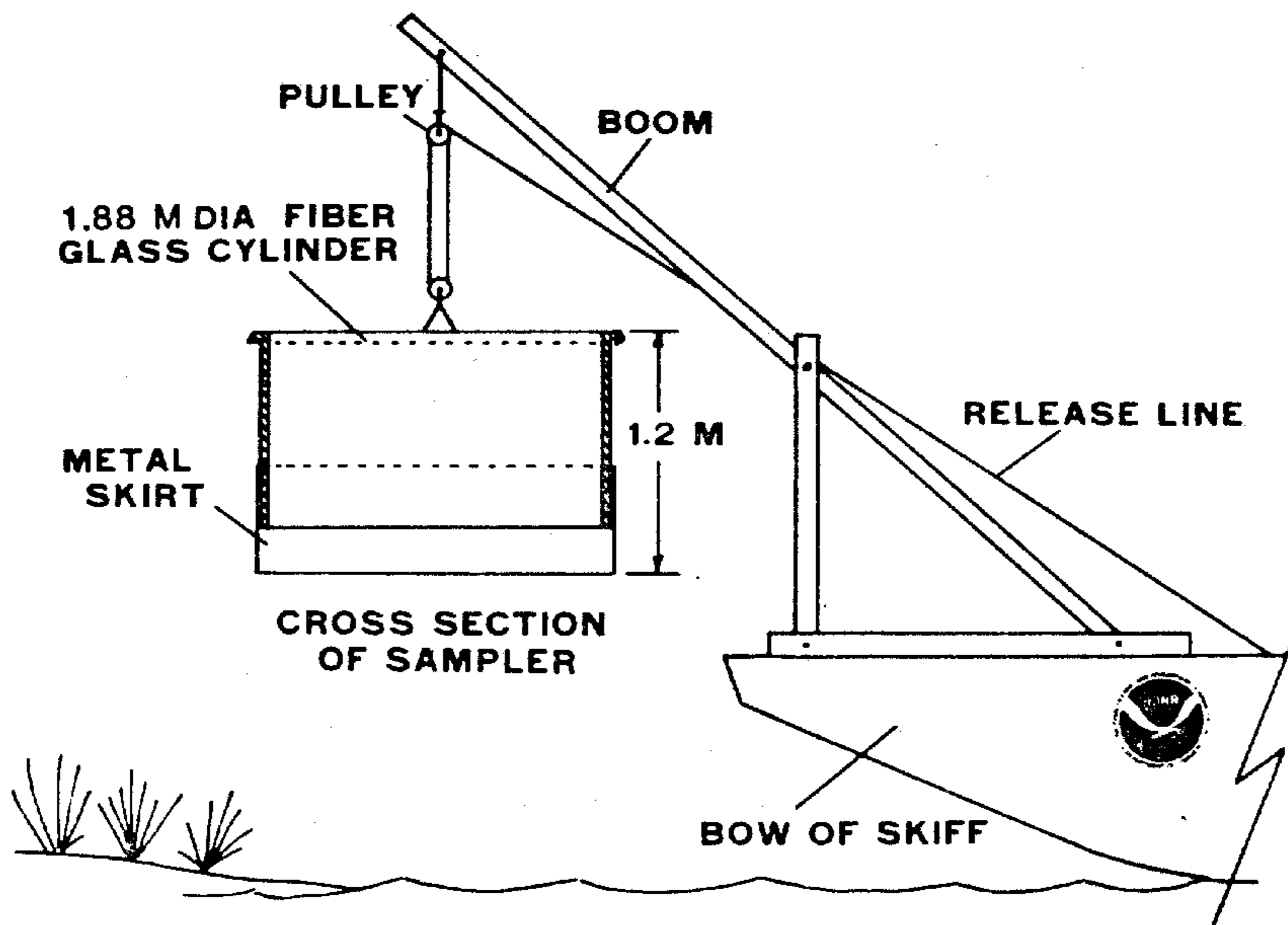
Figure 1. A cylindrical drop sampler used to measure shrimp densities in shallow water (from Zimmerman et al. 1984).
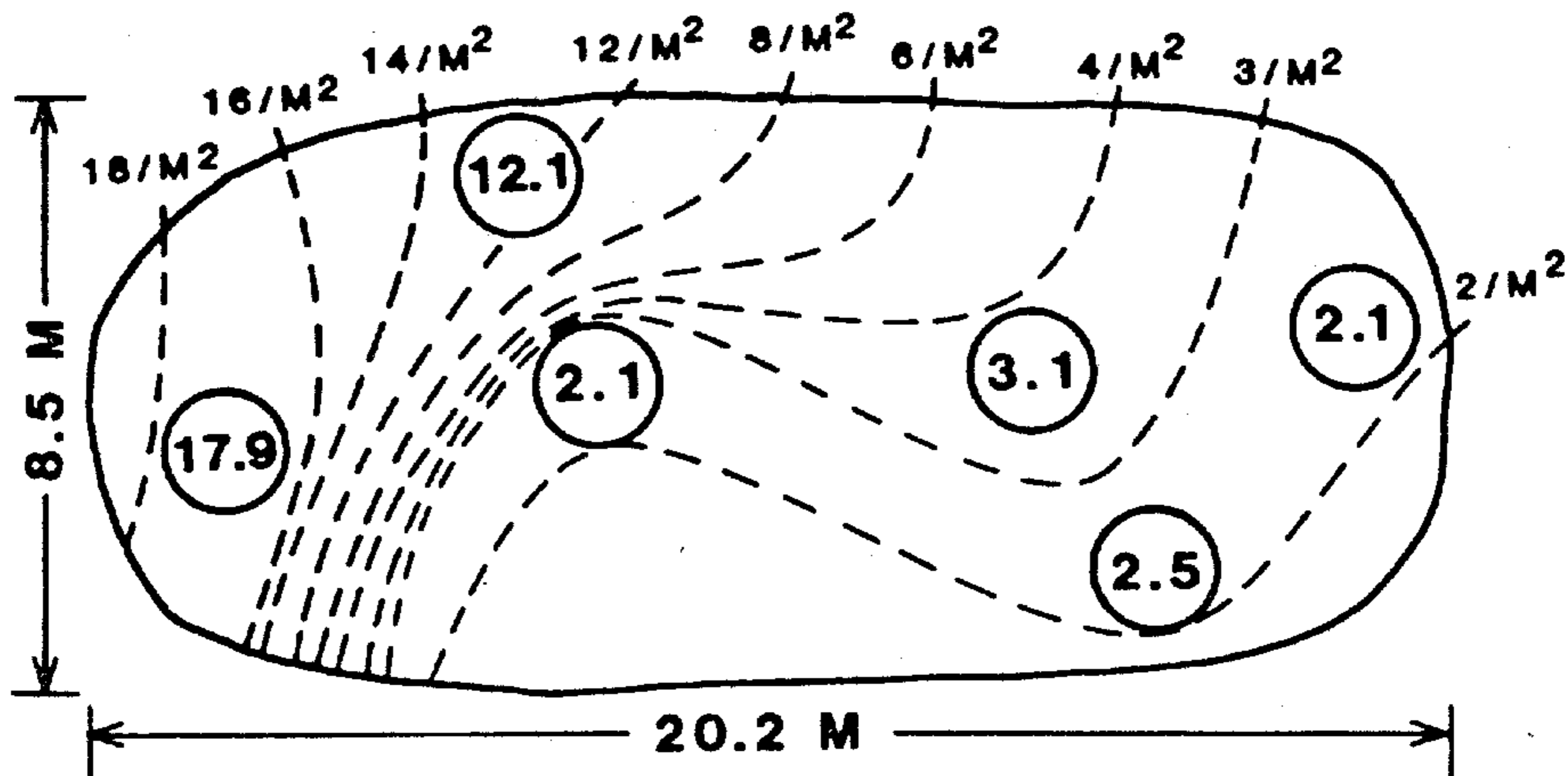
Figure 2. Density contours of white shrimp within a small pond contaning 1,200 individual shrimp. Shrimp densities (number/m^2) were obtained using 2.8 m^2 drop samplers (circles) and extrapolated to give an estimate of population size (1,166 shrimp).

trawl (3.0 m^2 per sample) and the drop sampler (2.8 m^2 per sample) at flood tide. The beam trawl was held on the bottom by hand, using one person on either side of the device, and pulled over a distance of 3.0 m. Water depth during sampling was approximately 35 cm intertidally and 65 cm subtidally. In separate tests that followed, 10 nonvegetated samples were each obtained with the drop sampler, the 5.5-m bag seine (110 m^2 per sample) and the 3.7-m otter trawl (75 m^2 per sample). Sets of samples from each gear were taken at random and simultaneously within the same area, and the catch per unit area for each of the seine and trawl collections was calculated and efficiencies estimated relative to the drop sampler. Comparisons were done within a large subtidal cove (approximately 250,000 m^2) with uniform water depth (80 cm), the same sediment type (muddy sand), and at low tide. Trawl and seine replicates were pulled over premarked distances of 20 m each. Typically, two drop cylinders were deployed about 10 m apart and the trawl was pulled on one side of the cylinders, about 30 m away, in one direction then on the opposite side in the other direction. Seine hauls were made parallel to the trawls over undisturbed bottom. For each gear type only those shrimp larger than 40 mm in total length were used in density calculations, since smaller shrimp were not effectively retained by the mesh in the otter trawl (13 mm^2) or bag seine (6 mm^2). The 1 mm^2 mesh in the beam trawl and drop sampler collection nets retained shrimp of all sizes.

Extrapolation of drop sampler densities to estimate shrimp population size was also compared to mark-recapture estimates within a natural bayou. In a study by Sullivan et al. (in press), 4,000 marked shrimp were released in a 36.4 ha temporarily closed bayou, and 5% were recaptured among unmarked shrimp after 18 h. These data were used to calculate total population size by the Petersen ratio (Bailey 1951). During the study, 16 drop samples were obtained from Spartina and nonvegetated habitats (equally divided) in the pond to measure densities. The resulting habitat-related densities were used to estimate population size for the entire area of the bayou. The methods and results of drop sampler versus mark-recapture comparisons are fully discussed in Sullivan et al. (in press).

RESULTS AND DISCUSSION

Recovery of marked shrimp from the drop sampler was 91% (SE = 3.3%, n = 4) in Spartina habitat and 98% (SE = 1.3%, n = 4) in nonvegetated habitat, and a t-test revealed no significant difference (P > 0.1) in recovery between habitats. The overall recovery mean (both habitats) was 94% (SE = 2.1%, n = 8). Error due to avoidance or entrainment during sampler deployment was not estimated. However, catch efficiency and accuracy of the technique appear to be high as reflected by our pond density estimate and comparison with

mark-recapture methodology. Actual mean density of captive shrimp in our 172 m^2 pond was 6.99/m^2. Calculated mean density from 6 drop sampler replicates was 6.78/m^2 (SE = 2.71). The relatively high standard error was apparently due to nonrandom distribution of shrimp within the small pond as demonstrated by density contours (Fig. 2). In a 36.4 ha bayou, the estimated shrimp population was 207,786 using mark-recapture and 245,000 using 16 drop cylinder samples. The 95% confidence intervals were between 180,884 and 234,688 for mark-recapture, and 91,300 and 731,000 for drop sampler (Sullivan et al. in press).

Compared against drop sampler densities, the 1-m beam trawl was 23% as effective in _Spartina_ vegetation for catching shrimp and 82% as effective on nonvegetated bottom (Table 1). Given equivalent area sampled, coefficients of variation (CV) from beam trawl densities were higher (in vegetation CV = 100%, nonvegetated bottom CV = 185%) than the coefficients of variation from drop sampler estimates (in vegetation CV = 42%, nonvegetated bottom CV = 100%).

In comparisons with other sampling gear, shrimp densities on nonvegetated bottom were 0.30 shrimp per m^2 using the drop sampler, 0.10 shrimp per m^2 with the 5.5-m bag seine, and 0.05 shrimp per m^2 with the 3.7-m otter trawl. Compared to the drop sampler, catchability coefficients were 33% (n = 10) for the bag seine and 17% (n = 10) for the otter trawl (Table 1).

The otter trawl is ineffective as a quantitative sampling device as confirmed by our data and those of others (Loesch et al. 1976; Kjelson and Johnson 1978). Loesch et al. (1976) compared _P. aztecus_ densities in Louisiana from mark-recapture estimates against estimates obtained with a 4.9-m wide otter trawl, and found trawl efficiency to be about 44.8%, varying between 36% and 53%. Shrimp catchability in trawls may be expected to vary temporally and spatially dependent upon shrimp behavior (burrowing, swimming, feeding) and environmental conditions (bottom type, water clarity, current structure, light intensity). In at least one study, water clarity has been shown to significantly influence catchability by an otter trawl (Nielsen 1983). Since otter trawls are difficult to standardize against variables that affect catch efficiency, they should not be used for quantifying stocks and predicting yields.

Seines are also used for quantification of estuarine populations (Modde and Ross 1983) and shrimp stock assessment (Benefield and Baker 1980; Benefield 1982). Kjelson and Johnson (1974) used a 354-m seine to sample marked fish in a shallow-water estuarine area and measured catch efficiency at 31 to 54% (95% confidence interval). These investigators noted that increased crew experience improved sampling efficiency from 10 to 47%. Despite the large area of each sample (10,000 m^2), which presumably reduces error due to patchiness

Table 1. Comparative gear efficiencies for sampling _Penaeus aztecus_ in a West Galveston Bay salt marsh (from Zimmerman et al. 1984).

| | Mean Efficiency | | | |
Habitat Type	[1]Drop Sampler	[2]Beam Trawl	[3]Bag Seine	[4]Otter Trawl
Spartina vegetation				
% Efficiency (Shrimp count, mean/m^2 + SD)	94%	23%	not	not
	(8.9 ± 3.7)	(2.2 ± 2.2)	operable	operable
Nonvegetated				
% Efficiency (Shrimp count, mean/m^2 + SD)	98%	82%	33%	17%
	(0.30 ± 0.30)	(0.25 ± 0.46)	(0.10 ± 0.06)	(0.05 ± 0.04)

Area sampled and number of replicates for each device were:

[1]$2.8m^2$ (n=22);   [2]$3.0m^2$ (n=12);   [3]$109m^2$ (n=10);   [4]$72m^2$ (n=10).

in natural distributions, Kjelson and Johnson (1970) were not able to greatly lessen variability and increase sampling precision (CV = 100%, n = 10). In another study, Weinstein and Davis (1980) estimated seine catch efficiency for three abundant fish species at 60.6 to 78.0% (respective standard deviations were 19.4 and 9.4%). Seining captured 70.3% of fish species present compared to 92.1% from a Rotenone sample. Our data (Table 1) suggest that for sampling shrimp, catch efficiency of seines is better than that of otter trawls, but it is not precise and also may be difficult to standardize. For purposes of yield prediction, seine data may not be adequate. Bay seine estimates of shrimp abundances taken by the Texas Parks and Wildlife Department throughout Texas bays, to evaluate size class structure (Benefield et al. 1983), do not appear to correlate closely with offshore catch given by Hamilton (1983, also see Bryan 1983).

Small bottom-nets, such as a 1-m wide beam trawl (Renfro 1963), 0.5-m wide marsh net (Pullen et al. 1968) or push nets (Allen and Inglis 1958), are probably better than large trawls for estimating shallow-water shrimp densities because area covered can be effectively measured and the small mesh in these nets can include smaller shrimp. With these devices, catch efficiency is relatively high (Table 1) and variability within sample sets (CV) is more likely to represent patchiness in distributions rather than error due to factors influencing catchability. Extending density estimates of small bottom-nets used in marshes to yield prediction appears to be feasible (Table 2, Table 3, Sutter and Christmas 1983), if tows are long enough to integrate sampling sites and conditions (such as bottom type and tidal stage) are carefully standardized. Since shrimp are juvenile transients in estuaries, sampling to estimate standing stock will be more effective in locations that are occupied for longer periods. For example, a 1-m beam trawl may be a better estimator of future yield when applied within nursery habitats (Sutter and Christmas 1983) than in migratory passes (Baxter 1963). Even in estuarine nurseries, however, conditions affecting densities and catch efficiency may vary. Since shrimp are often attracted to intertidal marshes (Zimmerman and Minello in press), densities on nearby subtidal bottom may vary according to tidal stage. In addition, brown shrimp burrow less at low light intensities (Lakshmi et al. 1976) making them more accessible for sampling at night and on cloudy days. Beam trawls and other small nets are designed for staying on the bottom, but an uneven seafloor can also cause some areas to be poorly sampled. These kinds of problems lead to variability in catch efficiency and loss of precision and accuracy when estimating population size. Under these circumstances, it may be advisable to restrict devices which estimate relative abundances to areas of uniform bottom without vegetation during night hours when the tide is low. An alternate solution is to avoid use of measurements with low catch efficiences and use methodology which

Table 2.   Marsh net and drop sampler estimates of estuarine postlarval brown
shrimp densities (latter part of March only) in selected Galveston
Bay marshes compared to offshore catch.

Year	Marsh (number/m^2)	Offshore catch (tails x 10^6 lbs
1979	**0.9	*18.8
1980	**8.7	*28.1
1981	**5.0	*40.0
1982	*0.9	*22.0
1983	*0.5	*17.0

*from National Marine Fisheries Service, Southeast Fisheries Center,
Galveston, Texas.

**from Texas Parks and Wildlife Department, Coastal Fisheries Branch,
Austin, Texas.

Table 3. A comparison of sampling gear and methods used to estimate juvenile shrimp abundances for predicting future yield.

Method	Advantages	Disadvantages
3.7 m otter trawl (relative abundance, area swept)	Simple operation; standard fishing gear; low manpower requirement; low cost; incorporates a large area; integrates natural variation in density patterns; may be used in deep water.	Low catch efficiency (30%), inaccurate, selective; may not always stay on bottom and area swept is difficult to ascertain; effectiveness is variable and highly dependent upon environmental circumstances; not useful in very shallow water or on vegetated bottoms; does not sample smaller shrimp sizes due to large mesh size; burrowed shrimp missed; cannot assure standard operation; nor distinguish between natural and mechanical sampling variability.
5-5m bag seine (relative abundance, area swept)	Simple operation; standard gear; low manpower requirement; low cost; incorporates a moderately large area; integrates natural variation in density patterns.	Low catch efficiency (50%), inaccurate, selective; effectiveness is variable and dependent upon operation and environmental circumstances; restricted to shallow-water; smaller shrimp may not be sampled by larger mesh sizes; burrowed shrimp missed; cannot distinguish between natural and mechanical sampling variability.
1-m beam trawl (relative abundance, area swept)	Simple operation; simple construction; low manpower requirement; low cost; stays on bottom; can measure area covered accurately; samples all sizes of shrimp; integrates natural variation in densities or samples discrete patches depending on length of tow; can be used in deep and shallow water.	Moderate catch efficiency (70%); selective; variable effectiveness dependent upon environ-conditions; burrowed shrimp missed; active avoidance by shrimp possible due to small mouth of net; ineffective on vegetated bottoms.

Table 3. continued

Method	Advantages	Disadvantages
2.8m^2 drop sampler (actual abundance, area enclosed)	High catch efficiency (95%) in all shallow water habitats including those with vegetation; actual densities measured; all shrimp sampled including those burrowed; natural patchiness in densities can be measured.	Operation and construction complex; high manpower requirement; high cost; each sample covers a small area and samples one patch; many samples needed to reduce variance term; restricted to shallow water.
Mark and recapture (actual abundance, indirect estimate)	Highly effective; accesses total population across all habitats and conditions; not restricted by water depth.	Operation complex; high manpower requirement; high cost; need population without immigration or emigration during measurement; estimates only among sizes captured; requires 10% recapture of marked animals; requires measurement of mortalities.
Commercial bait-shrimp index (relative abundance, indirect measurement)	Highly effective for shrimp within one month prior to harvest; low manpower requirement; low cost; no field sampling required; widespread coverage; numerous data points.	Requires monitoring of commercial bait fishery; uses otter trawl data and incorporates fishery biases; does not predict from early juvenile stocks.
Post-larval Index (relative abundance, direct measurement)	Simple operation; low manpower; low cost; provides earliest indicator of abundance using beam trawl or plankton net data; can be at immigration passes or in nursery areas.	Post larval abundance does not reflect future survival rates; temporal and spatial patchiness difficult to integrate during immigration; may need many samples.

consistently provides accurate density estimates through high catch efficiency (Table 3).

In vegetated habitats, such as marsh grasses and seagrasses, bottom nets are very inefficient (Table 1). Past recognition of this problem stimulated the development of a sled-mounted suction sampler (Allen and Hudson 1970) and drop net methodology (Hoese and Jones 1963; Gilmore et al. 1976). The drop cylinder sampler (Zimmerman et al. 1984), designed for estuarine marshes, combines valuable advantages of the suction sampler and drop net technique. Since it is possible to remove all organisms once enclosed by the drop sampler (including burrowed shrimp), valid comparisons of abundance relationships can be established between different shallow-water habitats regardless of bottom type.

The technique has greatly improved the accuracy of density measurements, but variability may be high for the drop sampler within sample sets (coefficients of variation). In this case error represents natural patchiness (Fig. 1) rather than variability in gear catch efficiency. At present, the problems posed by the technique are those created by the relatively small area sampled (2.8 m^2) and the effort required to obtain each sample. As presently designed, the drop sampler serves well for measuring densities in a small area and may be useful in calibration of catch efficiency for other techniques. However, the number of drop samples needed for estimating population size may not be practical for generating shrimp yield prediction. Yield prediction depends upon low variance among samples that measure densities. Due to the magnitude of natural density differences between patches of shrimp, and the variable number and size of patches, the number of drop samples needed to reduce variance is often large. Therefore, methods which cover larger areas (incorporate more patches) may be preferable. Use of a well calibrated 1-m beam trawl, redesigned to improve catch efficiecy, may be the best candidate for increasing precision and accuracy which is cost effective for shrimp yield prediction (Table 3).

There are other techniques available for estimating abundances and predicting yield, but most have restrictive limitations (Table 3). Estimation of population size by mark and recapture can be quite accurate (Hutchins et al. 1980; Sullivan et al. in press), but the necessary assumptions are often difficult to meet. This technique works best in a closed system where immigration and emigration are impossible during the mark-recapture event. Sullivan et al. (in press) blocked the entrance to a dead-end bayou on Galveston Island with a 46-m net (6-mm mesh) and estimated juvenile brown shrimp numbers by mark-recapture. Population size obtained using the Petersen ratio (Bailey 1951) agreed closely with our independent estimate acquired using the drop sampler. In another

investigation, Hutchins et al. (1980) checked mark-recapture estimates of shrimp numbers in experimental ponds against actual densitites. They found estimates to be inflated by about 12% but within error limits (SE = 9.1%). Aside from the few sites available within any estuarine system for applying mark-recapture methodology, the technique is often costly and requires an intensive effort. In addition, smaller shrimp are usually not marked (tagging is rarely practiced on individuals less than 40 mm in length); therefore, assessment does not include the entire population. Enclosing nets and drop nets also have been used to estimate sizes of estuarine populations (Hellier 1958; Hoese and Jones 1963; Kjelson et al. 1975; Matlock et al. 1982), but with limited success. The main problem has been ineffectiveness in removing organisms once entrapped. Application of toxic substances, such as rotenone for fish, appears to improve resolution of estimates but even these are not entirely effective (Weinstein and Davis 1980, Matlock et al. 1982). A successful bait shrimp index also has been developed for predicting yield (Klima et al. 1982) but it has diminished value since data are required just before (within 1 month) shrimp attain sizes large enough for the primary commercial harvest. The most useful estimators of predictive yield will target postlarvae and early juveniles several months prior to entry into the fishery.

Shrimp yield prediction must be precise to be reliable, and improved precision incorporates low variance and consistency in measuring population size. By acquiring such estimates on early recruits together with measurements of environmental factors that influence shrimp survival (Saila et al. 1982; Sutter and Christmas 1983) perhaps the best yield projections can be made. For most predictors, the precision of estimates is highly dependent upon gear bias and circumstances of use. All sampling devices that measure relative abundances assume that catch efficiency is uniform in time and space. This assumption, as has been reviewed in our investigation, is usually untrue. Catch efficiency is usually low and rarely standardized for consistency. The result is that errors are incorporated into estimating population size, and both precision and accuracy in predicting future yield are lost. The best methods are those which have high catch efficiency and low variance and access the early juvenile population (Table 3).

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